

Mr. Main's observations with the splendid Oxford Heliumeter give as the most probable result, the large fraction of $\frac{1}{37.59}$ for 1862. This excellent astronomer has continued his observations during the late opposition. My own attempts to obtain the ellipticity with the micrometer eyepiece reading to $0''.2$ of arc failed to give satisfactory measures. The ellipticity, indeed, seemed to be small, and was merely observable, not really measurable or even to be approximately estimated by the help of this apparatus.

IV. "Notices of the Physical Aspect of the Sun." By JOHN PHILLIPS, M.A., LL.D., F.R.S., F.G.S., Professor of Geology in the University of Oxford. Received January 13, 1865.

PART I.

Frequently, during many years, the peculiarities of the physical aspect of the sun have arrested my attention, and induced me often to sketch and sometimes to measure; but until Mr. Cooke furnished me with the accurate and convenient equatorial which I now employ, there seemed little hope of my being able to draw correctly or observe systematically. During some late occasions I have endeavoured to obtain trustworthy representations not only of some of the darker tracts, denominated "spots," and the brighter parts which are near them, called "faculæ," but also of the general uneven groundwork of the sun's disk.

In tracing the path of a "spot" across the disk of the sun, I employ a Kellner (positive) eyepiece of about 50 linear, on which are engraved five transit-lines, at intervals of about $\frac{1}{11.7}$ of the sun's diameter, and therefore, near the centre of the disk, about equal to 10° . Having, with this eyepiece applied to the diagonal sun-glass, and the clock movement, determined the position of the spots, I replace the Kellner by ordinary (negative) eyepieces, whose powers range from 75 to 300, the latter being seldom beneficial except for objects near the limb, and in very favourable weather—which, in my experience, means a partially clouded sky, westerly winds, and morning hours by preference. Some of the clearest views which I have experienced were had in the intervals of storms and snow-clouds—the slowly drifting snow-flakes of those clouds being visible as dark spots in the field of view, when the eyepiece was adjusted to their very moderate distance*.

I present a diagram† showing the appearance of the sun's disk on the 29th of March, 1864, and other sketches of the bright and shady parts of the surface. From the variations in the appearance of the spots, faculæ, and ground surface, many suggestions arise; but I limit myself on this occasion to some inferences which appear justified by the observations of the least variable of them. So great is the diversity in the short

* I have occasionally employed the telescope to measure the distances and heights of clouds, employing for the purpose a well-known formula.

† Of the drawings accompanying this paper, which are referred to by numbers, Nos. 3, 4, and 5 are given in Plate III.; the rest are preserved in the Archives.

history of these ephemeral phenomena, that no view of their origin and progress can be held to be so well established at present as to exclude the consideration of other speculations.

Faculæ.—Near the edge of the solar disk, and especially about spots approaching the edge, it is quite easy, even with a small telescope, to discern certain very bright streaks of diversified form, quite distinct in outline, and either entirely separate, or coalescing in various ways into ridges and network. When, near the limb, the spots become invisible, the undulated shining ridges and folds to which I refer still indicate their place—being more remarkable thereabout than elsewhere on the limb, though everywhere traceable in good observing-weather* (see Plate III.). *Faculæ* are the most brilliant parts of the sun; they appear of all magnitudes, from barely discernible softly gleaming narrow tracts 1000 miles long to continuous complicated and heapy ridges 40,000 miles and more in length, and 1000 to 4000 miles broad. By the frequent meeting of the bright ridges, spaces of the sun's surface are included of various magnitudes and forms, somewhat corresponding to the areas and forms of the irregular spots with penumbrae. They are never regularly arched, and never formed in straight bands, but always devious and minutely undulated, like clouds in the evening sky, or irregular ranges of snowy mountains. When carefully studied with powers of 75, 135, and 180, which are very effective, the ridges appear prominent into cusps, and depressed into hollows; the cusps having brighter and more shady sides, so as not to be unlike some forms of branching crystallized native silver.

Ridges of this kind often surround a spot, which appears the more conspicuous from the surrounding brightness; but sometimes there appears a very broad white platform round the spot, and from this the white crumpled ridges pass in various directions (see Diagram, October 16, 1862, No. 2). Toward the limb the ridges appear parallel to it; further from it, this character is exchanged for indeterminate direction and lessened distinctness; over the remainder of the surface they are much less conspicuous, but can certainly be traced as an irregular network, more or less disguised by the minuter structure which has been described as porosity. I present selected sketches of the appearances mentioned. In considering the *faculæ* with attention, I remark that they preserve their shapes and positions with no material change during a few hours of observation, and probably for much longer periods, since after rotation through 15° the main features appear much the same as before.

The *faculæ* look like half-shaded snowy mountains and like half-illuminated clouds, and one might suppose that in either of these cases their

* In a recent communication to the Royal Society (Proceedings, vol. xiii. p. 168), Mr. Balfour Stewart remarks that, in the photographs of the sun taken at Kew, it appears to be a "nearly universal law that the *faculæ* belonging" to a spot "appear on the left of that spot, the motion due to the sun's motion of rotation being across the picture from left to right." I find that my sketches support this view to the extent that the *faculæ* which follow a spot appear in several cases more prominent than in others. Perhaps in a photograph those only can be traced, or the differences may seem to be greater.

elevated parts should project beyond the general circular outline. This I have never seen to happen; and if a little attention be given to proportions, it will appear very unlikely to be often observed. If the breadth of one of the ridges be taken at 4000 miles, its average slope 30° , and its height at a quarter of the breadth, viz. 1000 miles, this, if projected beyond the circular disk, would no doubt be discernible, for it would be equal to $\frac{1}{850}$ th of the sun's diameter, or above $2''$. But the number of the ridges is so great, and the crowding of them very near and on the limb so close, that it is hardly possible, on the average, for any ridge to be seen much above its fellows, whether the faculæ be in the atmosphere or in the body of the sun.

The continuous circularity of the sun's limb is therefore no sufficient argument in itself against the faculæ being much raised above the general surface; and it seems worth while to make special researches as to the manner in which faculæ come on and go off, in the hope of finding some case which shall be decisive.

General Ground.—In examining the interspaces between the faculæ in the parts towards the limb, it is not easy to see more on the surface thus inclined to the visual ray than a certain unevenness of tint; under a higher angle of incidence, toward the interior of the disk, this ground acquires more evident partial shades and lights—a sort of granulation difficult to analyze, especially if, as is most frequent, the edge of the sun shakes with varying refraction. If all be quite steady, however, the eye discerns both the ramifications of faculæ and the granulation of the interspaces, and by degrees acquires the power of seeing this easily and clearly. Under this condition, the perpetual motion and inconstant agitation, so often described, by no means appears to be a characteristic phenomenon, but rather as an exceptional trouble to the observer, arising from inconstant refraction, fatigue of the eye, or shake of the instrument. These difficulties increase rapidly with high powers; but with a power of 100, and good weather, the sun's face does not appear to be much obscured by this kind of intestine agitation.

What is seen appears in the diagram for April 2, 1864, as well as I can represent a structure so minute and perplexing. The ground of the whole is a surface of complicated small lights and shades, the limits of which appear arched or straight or confused according to the case; and the indeterminate union of these produces sometimes faint luminous ridges, the intervals filled up by shaded interstices and insulated patches of illuminated surface. One eminent observer*, seeing these under a high power, has compared them to willow leaves, unarranged except where they conform in some degree to the great features of the spots. Using the same kind of analogy, one might say they seem to resemble any somewhat uneven surface composed of separate masses, presenting themselves in all directions and at different levels. Being of all shapes, they must generally have one transverse measure greater than the other, and thus

* Mr. Nasmyth.

appear for the most part oblong, but with no systematic concurrence of direction. The comparison used by another astronomer*, of an irregularly heaped surface of rice, here collected into ridges, there sunk into depressions which seem to be occasionally deepened into pits, has its advantages. But upon the whole I prefer to be content with the less definite analogy to an irregular granulated and pitted surface, composed of small prominent lights complicated with intermediate shades of different intensities.

PART II.—*Details of Spots.*

In the midst of the general ground thus described, spots make their appearance, grow, change, and decay under the observer's eyes. Seldom indeed, as once to Mr. Carrington, does it happen that a spot appears suddenly; its growth, change, and decay are all usually slow—too slow to be positively noted and measured except at intervals of hours and days. We notice occasionally spots of minute size which have no surrounding penumbra; these may be either very black or only dark. These often occur in considerable numbers near a large spot well enclosed by penumbra, as in spot No. 2, 29th March (Drawing No. 7). On the 30th of March one of these had acquired a slight penumbra, several of the others had disappeared. The several small spots represented (Diagr. No. 6) amidst a mottled surface of faculæ and granulations had no penumbra; one was dark, but not black. Some of the spots here referred to appear to be less than 500 miles across, and many are less than 1000. They are occasionally in twins, and not unfrequently disposed in groups which may eventuate in a spot, or in a long sinuous tract having some relation of origin to greater spots near them. The greater spots with large penumbral regions have usually very irregular boundaries, and equally irregular black nuclei. In them it is quite usual to perceive two, three, or more nuclei; but in such cases the term nucleus is but little fitted to describe these often narrow winding and branching spots which appear within the irregular space. The boundaries of that space are in a certain degree conformed to the black nuclei. Many large spots of this kind undergo very considerable changes in the course of one day. A complicated spot which measured about 20,000 miles across on the 29th of March, lost its penumbra and was reduced to separate nuclei on the 31st; while a curved collection of small dots near it was concentrated to a small group, and two other obscure dots expanded a little and became three. In this state, with but slight further change, they all passed across 60° of arc.

In complete contrast with these examples is the spot No. 4 [in the diagram of March 29], which with very little observable change in itself, and with no additional productions near it, has been traced across the sun's disk through a third of the circumference. I present drawings of this spot as it appeared with powers of 75 and 135, for the purpose of marking the unusual persistency of its characters, and describing its relations to the

* Mr. Stone.

surrounding tracts of the sun's surface. It will be observed that the nucleus is black, not quite uniformly so, however, but with some inequality of tint; and that it is branched or notched at the edges, in this respect exhibiting *some* differences at different dates, which I do not think are due to any error or uncertainty in the sketches. The ring space round the spot, though not quite uniform, presented no inequalities that I could mark; the border was grey, striated, and unevenly extended into the surrounding tracts. These unevennesses appeared to me to be little varied, during several days. The striations and extensions in a radiating direction correspond to what Mr. Dawes calls by the picturesque name of "thatch"—a name singularly appropriate, if this border overhangs, as is often supposed, a cavity or depression. This "thatch," according to Mr. Nasmyth, is formed by the concurrent outlines of his "willow leaves"; but Professor Airy, in commenting on Mr. Stone's recent communication to the Royal Astronomical Society, is reported to have called attention to the fact that the rice-like aggregations were "quite distinct from the thatching so graphically described by Mr. Dawes in the penumbrae"*.

Until the opportunity shall have occurred to me of observing and drawing the edges of penumbrae and nuclei under a sufficient variety of circumstances, I must not offer to reconcile these apparently different opinions; at present my impression is that the "thatched" edges of the penumbra are only broken parts of the general groundwork of the body of the sun; which may be, or rather must be supposed to be very unequally luminous in different parts, the depressed and granulated parts emitting the least light.

The spot No. 4 on the Diagram for March 29 was first seen near the edge of the sun, surrounded by faculae of great brilliancy†. This spot had the elliptical outline due to its position; the black nucleus was central; the border was shaded and striated; between the border and the nucleus was a clear bright space, not then appearing grey or dusky. As the spot moved on toward the central part of the disk, the oval became less and less eccentric; the nucleus remained central, and the border retained its dusky and striated aspect; but the ring round the nucleus lost its brightness, and took up more of the grey tint which belongs to the general surface of the sun when a very dark glass is employed‡.

If these circumstances be well considered, they appear sufficient to prove that the spot taken as a whole is not sunk very much below, or raised very much above, the general level of the region. For were its interior part sunk very much below the border, it would have presented to the eye in passing from near the edge toward the centre the appearances sketched in

* 'Reader,' 2nd April, 1864.

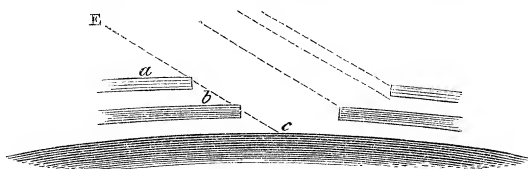
† The drawings are made with the solar eyepiece, placed as in a Newtonian reflector, on the western side of the telescope. They do not, therefore, correspond with drawings or photographs taken by the ordinary arrangement without diagonal reflector.

‡ The full opening of the telescope (6 inches) being employed for the sake of exact definition, a very dark glass is required if the sun be clear.

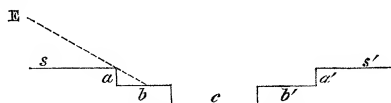
the annexed diagram, not those which really occurred, as shown in the diagram already referred to.



If we regard the spot as marking an opening in a bright photosphere, through which the dark body of the sun is seen within a terraced penumbra, as represented in the diagram of Sir J. Herschel * (here copied), it is obvious

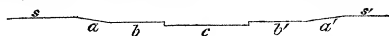


that toward the edge of the sun, when the line of sight, $E c$, forms a very small angle with the surface of the sun, one side of the supposed terrace b will become invisible if the intervals of height between b and a be very considerable, and in the same way a part or the whole of c will be lost. The photosphere of the sun, then, if it exist, appears not to have the enormous depth sometimes ascribed to it; or if we suppose the spot, with its ring and border, to be a terraced concavity in the solid globe of the sun as under, with very steep sides, and breadths, $a=1$, $b=2$, $c=3$, the whole



from a to a' being 13,500 miles, it will be obvious that the difference of the levels of a and b cannot have so great a proportion to the sun's diameter as the crater-walls of the moon bear to the diameter of that satellite, or else cannot have anything like their steepness. The moon's crater-walls are in height $\frac{1}{2000}$ or even $\frac{1}{10000}$ th of the diameter, and often very steep. On the sun the same proportion would give cliffs 400 or 800 miles high, and with the spot in a position 60° from the centre of the sun, such cliffs would on one side conceal half or more of one side of the terrace (b), while the other side (b') of the terrace remained entirely visible.

If we suppose that a is not a steep cliff but a prolonged slope, so that even toward the edge of the sun the whole of the interior area may be seen, the limit of the difference of level between the general surface (s) and the interior terrace ($b b'$) can be calculated. For example,



In former observations of remarkable spots (1862), and again in 1863

* *Outlines of Astronomy* (Ed. 1833), pl. 3. *d.*

and 1864, I have several times noticed this persistence of the elliptically contracted spot with its nucleus, equidistant from the borders, very near to the edge, both coming on and going off, certainly within 10° of the edge, from which it may be inferred that in that case the angle of inclination of the edge of the spot to the general surface could not be greater than 10° . Taking the case of 10° , and applying it to the spot now under consideration, the difference of level in miles between s , the general solar surface, and b , the ring terrace, might $= a \sin 10^\circ = 300$ miles, but could not exceed it. This result is represented in the preceding diagram.

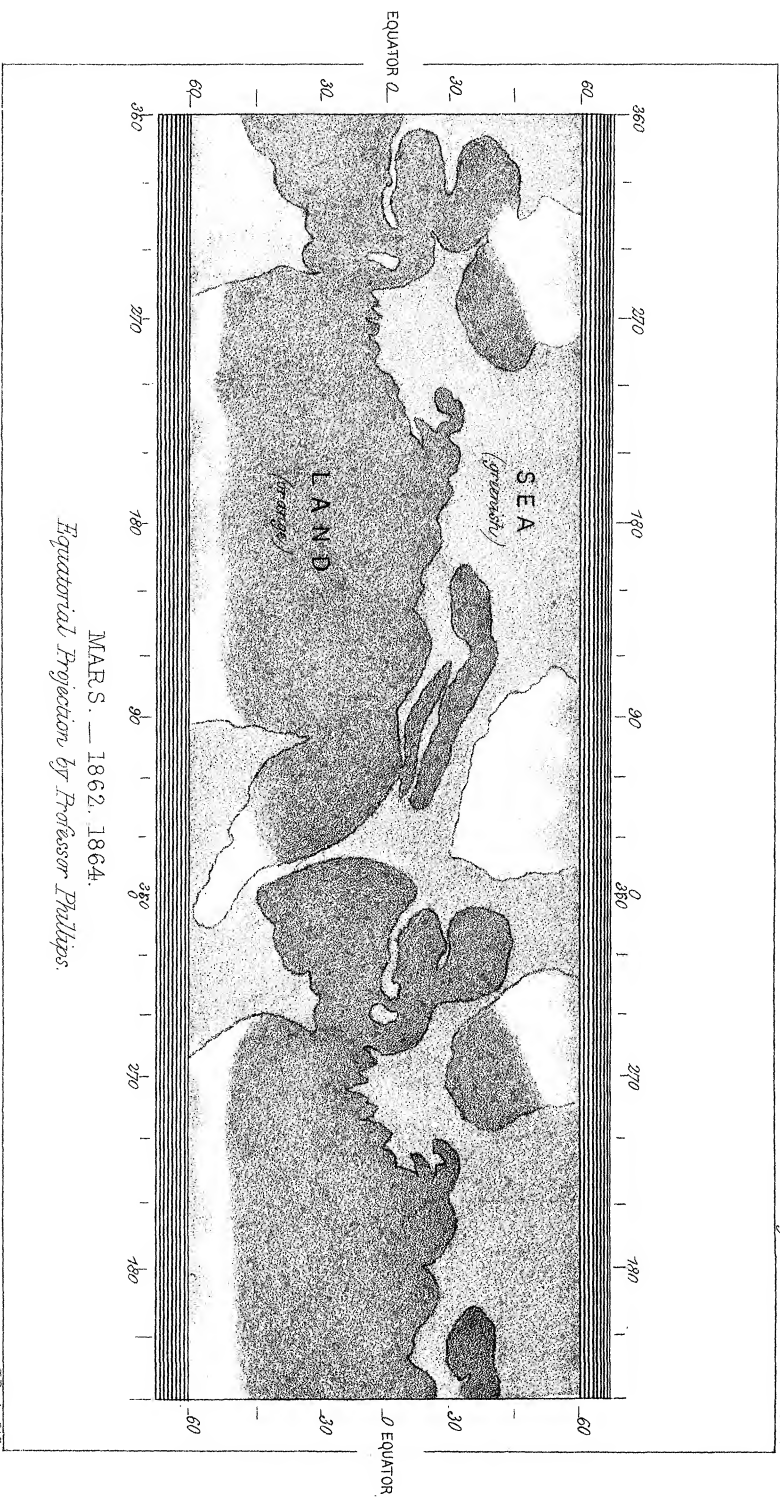
Nor can the spot be sunk in a deep saucer-shaped concavity like

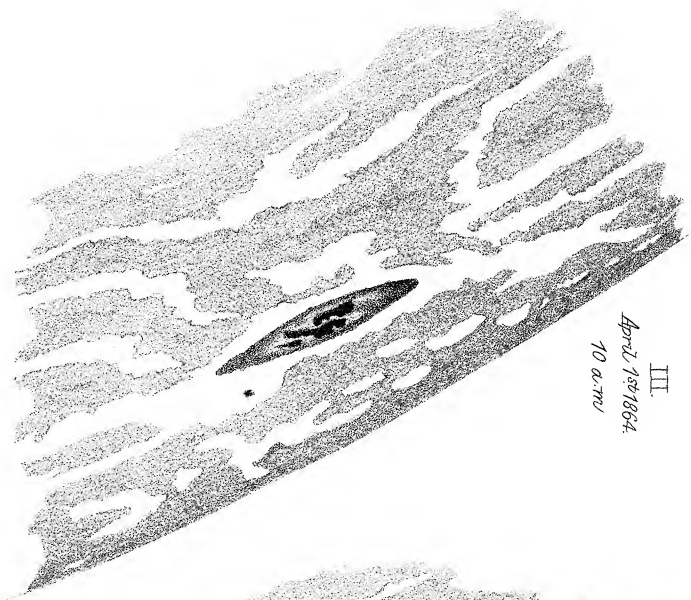


for the same reasons.

But, however deeply the spot may be sunk below the surface of the sun, no notch could appear in consequence of that at the limit of the sun; for before reaching the limb the angle $a E a'$, under which it is seen from the earth (E), would become invisibly small, and the space $a - a'$ become invisible. Even if the sides a and a' were very unequal in level, the leading edge a' being depressed, this would make no visible notch on the limb of the sun, except the spot were enormously large, as well as very deep—much greater for instance than 40,000 miles. Except in very rare cases, then, the sun's edge must always appear truly circular, notwithstanding the depressions of the spots and the elevations of the faculæ.

Finally, I remark that the spots may appear black, dark, grey, &c., not because they really are so dark as they seem, but that, being less luminous than other parts of the disk, they acquire this relative darkness under the operation of the optical apparatus, and the influence of contrast on the sensation. An extremely good way of viewing the spots is to project the sun's image on to a smooth porcelain screen, about a foot or 18 inches in diameter; very smooth white paper answers very well. Thus tried, every imaginable degree of relative darkness appears in the spots, and the faculæ come out bright and distinct. In this experiment, the spots seem so dark in the nuclei as to suggest the hypothesis that the parts of the sun to which they correspond really emit specially heat-rays, below the range of refrangibility which brings to our eyes light and the power of sight. Heat-rays and light-rays come to the earth together, but that is no reason for thinking they must spring in mixed pencils from every part of the sun equally. In my way of considering it, this rather confirms the idea of the deep black nuclei being the sun's body, the penumbrae that body partially seen through the atmosphere, and the facular region transmitting to us rays which have acquired a higher refrangibility than that with which they started, by a peculiar change in the sun's atmosphere, which may justly be called his photosphere.





Facula.

Spot approaching limb.

Spot nearing the limb.

Spot disappearing.





MARS. — 1862 1864
Equatorial Projection by Professor Phillips

III

April 1st 1864

10 a.m.

IV

April 1st 1864

3 1/2 p.m.

V

April 2nd 1864

11 a.m.

Faculae

Spot approaching limb

Spot nearing the limb

Spot disappearing